TDI settings and protection

TDI: protects LHC from miskicked injected beam (setting up, timing errors, kick setting errors, MKI failure). In position during injection process only.
TDI jaws set around injected beam
Setting the TDI

• Find the axis of the circulating beam with pilot bunches
  – Measure the beam position with BPMs?
  – Measure the losses with the TDI jaws and BLMs??

• Set the jaws symmetrically about this position

• Inject the full batch…

• Consider MKI flashover failure (worst case)
In a perfect world...

...the TDI can be positioned nicely between the edge of the halo and the aperture
Unfortunately, (as we all know) the world is not perfect.

- plus random errors on the injected beam position / angle (0.2 $\sigma_y$)
- plus optics errors changing the phase advance from MKI to TDI ($\leq 20^\circ$)
2 TCLIs per IP at 360±20° from TDI foreseen to protect against MKI-TDI phase errors – but now location at +20° next to Q7 is impossible…
So… do we need 2, or 1, or even 0 TCLIs?

- Checked protection afforded by TDI **ONLY** with the ‘realistic’ errors

- Also checked protection afforded by TDI plus **ONE** TCLI at 360° from TDI
  - Some hope since TCLI 1m Cu with better precision

- Also checked protection afforded by TDI plus **TWO** TCLIs at 360±20° from TDI
Checked particles outside aperture for these errors, by scanning MKI kick to obtain highest transmission…

<table>
<thead>
<tr>
<th>Assumed errors:</th>
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<tr>
<td>Injection error ±0.2 σ</td>
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<tr>
<td>MKI-TDI phase error ±0-20°</td>
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<tr>
<td>Orbit – TDI/TCLI precision ±0.1mm (±0.17 σ)</td>
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<tr>
<td>TDI mechanical error ±0.2mm (±0.33 σ)</td>
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<tr>
<td>TCLI mechanical error ±0.075mm (±0.13 σ)</td>
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<tr>
<th>Other assumptions</th>
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<tr>
<td>288 x 1.15 x 10^{11} p+</td>
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<tr>
<td>Gaussian beam in Y, Y’</td>
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<td>Extent of secondary halo: 7.88 σ</td>
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<td>Vertical aperture limit: 8.2 σ</td>
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<td>Damage limit 2% of full batch</td>
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Regions where beam outside 8.2 $\sigma$ exceeds damage limit (2% of total) as a function of MKI kick and TDI advance, for 0, 10 & 20 degree MKI-TDI phase errors.

TDI only

TDI with TCLI at 360°

TDI with 2xTCLI at 360±20°

Note: the TDI NOMINAL position (i.e. the ‘setting’) is 0.5 $\sigma$ larger.
What does this mean in terms of likelihood for damage?

- Assume 1 MKI flashover per 8 magnets per year (expected rate extrapolated from measurement on 1 prototype magnet)
- 1.09 $\sigma$ deflection per MKI cell ($2 \times I_{\text{nom}}$)
- 33 cells per MKI magnet
- 2 dangerous kick regions (grazing upper or lower TDI jaw)
Expected dangerous events per year (total for the 2 injections) as a function of TDI/TCLI setting, for 0, 10 & 20 degree MKI-TDI phase errors

Note: the TDI NOMINAL position (i.e. the ‘setting’) is 0.5 $\sigma$ larger.
Zero TCLIs

If MKI-TDI phase error $\leq 10$ degrees,
And TDI can be set at $7.7\sigma$ (i.e minimum position at $7.2\sigma$)
Then risk of damage due to MKI flashover every 5 years without TCLIs.

One TCLI at 360° from TDI

If MKI-TDI phase error $\leq 20$ degrees,
And TDI can be set at $7.7\sigma$ (i.e minimum position at $7.2\sigma$)
Then risk damage due to MKI flashover every 20 years with one TCLI.

Two TCLIs at 360 ±20° from TDI

If MKI-TDI phase error $\leq 20$ degrees,
And TDI can be set at $7.9\sigma$ (i.e minimum position at $7.4\sigma$)
Then risk damage due to MKI flashover every 40 years with two TCLIs.

1. Always assume here that MKI-TCLI phase advance is perfect……but should also check for errors in TDI-TCLI phase advance. OB to provide an idea of expected errors.

2. Risk of damage to TCLI itself non-negligible… to be evaluated in similar way.
What about positions for TCLIs?

• Next to Q6 is OK (340 or 360°)

• Next to Q7 is out… (DFBX interference)

• Next to D1 (180 +20°)? But 2 beams in same chamber… full analysis needed for TDI / TCLI / TCDD / TCT

• 640 degrees…. into continuous cryostat. Ugly.

• So one TCLI is OK, but 2nd only fits neatly at D1…
So where do we go from here?

- Reserve (again!) space next to Q6 for one TCLI
- Investigate feasibility of having TDI advanced to ~7.2 $\sigma$
  - Expected particle load
  - Effect on collimation system
  - Effect on TDI (activation, heating)
  - Effect on insertion (quenches?)
- Investigate feasibility of combined TCLI / TCT at D1 (anyway similar study being done for TCDD / TCT)
- Check damage expectation to Cu TCLI under the same assumptions
- Obtain realistic estimate of expected optics errors (MKI-TDI-TCLI phase advances)
- Suggestions for improving positioning tolerances welcome
  - Any optimists out there?